Photonic Band Gap Materials: Engineering the Fundamental Properties of Light

Sajeev John
Department of Physics
University of Toronto
Canada

www.physics.utoronto.ca/~john

Photonic Band Gap (PBG) materials are artificial, periodic, dielectrics that enable engineering of the most fundamental properties of electromagnetic waves. These properties include the laws of refraction, diffraction, and spontaneous emission of light. Unlike traditional semiconductors that rely on the propagation of electrons through an atomic lattice, PBG materials execute their novel functions through selective trapping or "localization of light" using engineered defects within the dielectric lattice. This is of great practical importance for all-optical communications and information processing. Three dimensional (3D) PBG materials offer a unique opportunity for simultaneously (i) synthesizing micron-scale 3D optical circuits that do not suffer from diffractive losses and (ii) engineering the electromagnetic vacuum density of states in this 3D optical micro-chip. This combined capability opens a new frontier in integrated optics as well as the basic science of radiation-matter interactions.

We review recent approaches to micro-fabrication of photonic crystals with a large 3D PBG centered near 1.5 microns. These include direct laser-writing techniques and holographic lithography. We review the concept of a hybrid 2D-3D PBG hetero-structure in which a 2D photonic crystal micro-chip layer is suitably lattice matched and embedded within a 3D PBG material. This microchip layer contains optical wave-guides and optical micro-cavities that enable frequency selective control of spontaneous emission of light from atoms. Unlike traditional wave-guides that confine light in a high refractive index medium using total internal reflection, these air-wave-guides operate using the principle of light localization for confinement of light along a low refractive index path.

We demonstrate a nearly universal approach to ultra-dense, three-dimensional, integrated optics in general 3D PBG architectures. These 3D optical circuit paths are constructed using broadband, loss-less, chip-to-chip interconnects between 2D micro-chip layers, intercalated within the 3D PBG host material. Unlike electronic micro-circuitry, each air-wave-guide path can simultaneously conduct hundreds of wavelength channels of information, throughout the 3D micro-chip.

In addition to exhibiting diffraction-less flow of light through micron-scale bends, this optical micro-chip allows the engineering of very large and abrupt changes in the local electromagnetic density of states as a function of frequency. This leads to unprecedented frequency selective control of spontaneous emission, modification of the blackbody radiation spectrum, and some fundamentally new optical functions unattainable in conventional photonics.